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Published in:
Proceedings of the IEEE 2000 International Geoscience and Remote Sensing Symposium

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2000

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
de Jong, J. J. M., de Groot, H. W., Klaassen, W., & Kuiper, P. J. C. (2000). Radar backscatter change from an ash in relation to its hydrological properties. In *Proceedings of the IEEE 2000 International Geoscience and Remote Sensing Symposium* (Vol. 7, pp. 2927-2929). University of Groningen, Centre for Isotope Research. https://ieeexplore.ieee.org/document/860293

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Radar Backscatter Change from an Ash in relation to its Hydrological Properties

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ABSTRACT

A ground-based X-band radar was directed almost horizontally into the top of a mature ash during 5 months. The aim was to relate radar backscatter to hydrologic properties of leaves. The results show that: (1) Due to the retention of rain on the surface of leaves, the backscatter increased temporarily during and after showers. (2) The backscatter decreased the first days after a shower. This decrease is attributed to depletion of internal water-storage tissues. (3) The backscatter increases towards the end of the season. This trend is related to a decreased transpiration rate and increased water content of leaves.

INTRODUCTION

Radar backscatter of trees is related to the dielectric constant of tree tissues. The dielectric constant depends strongest on the water content of these tissues [1]. The water content is coupled to weather by transpiration [2, 3]. During and shortly after rain some water retains on the surface of for the most part leaves [4]. The dielectric constant of a leaf with a water film on the surface is calculated by averaging the leaf and water film dielectric constants [5]. The retained water is in perspective of radar backscatter therefore part of the leaf. As in-vivo measurement techniques of the dielectric constant of leaves do not exist, less is known of weather-related changes in backscatter of leaves. To fill this gap in knowledge, the backscatter of an ash (*Fraxinus Excelsior*) was monitored with X-band radar. The aim is to relate radar backscatter with water content of leaves, either inside the leaf tissue, or on the surface due to rain. The experiment started in July 1999 when leaves were fully developed, and lasted till December 1999, one month after leaf-fall.

SITE AND DATA COLLECTION

The mature ash is part of a tree line that borders the experimental field of the Biological Center of the University of Groningen. The ash is 20-m height and has a crown projection of 250-m^2. Radar backscatter was monitored with ground-based VV-polarized X-band radar (METEK MTR-1), which was pointed at the leafy upper-canopy. The distance between the radar and the tree was 60-m. The radar-beam diameter was in the tree 3-m. The backscatter is recorded in linear units, and averaged over a certain period (hour, day) to eliminate fading. The averaged backscatter is next divided through the 5-months mean backscatter, and converted to decibel. This results in the backscatter change relative to the mean backscatter. Independent samples are needed for averaging. It is assumed that observations are independent as long as the tree moves in the wind. Measurements below a certain windspeed are therefore excluded.

A weather station was installed halfway the radar and the ash. Measured were windspeed (u), temperature (T), humidity (H), net radiation (Q_n), incoming short-wave radiation (Q_s) and rainfall (P). The weather station was also equipped with a leaf-wetness sensor (Campbell 237). This is a small circuit-board with interlacing copper-fingers. Condensation or rain lowers the resistance between the fingers. It was empirically found that the wet sensor had a resistance below 1kΩ, and a dry one a resistance above 5 kΩ.

The water content of the leaves was regularly measured early in the morning and occasionally every hour from early in the morning till late in the evening. The gravimetric water-content (m_g) of leaves was obtained by picking 10 leaflets from the pinnate leaves of the lower branches, and weighing them within 5 minutes after sampling. The leaflets were next dried in an oven and weighted again. Transpiration (E) of the tree is calculated from the weather data with the Penman-Monteith equation [2]. The required stomatal conductance was measured and subsequently modeled according to [6].

RESULTS

Fig. 1a shows the daily mean temperature and precipitation. A maximum temperature of 30° C was reached at 19 July, 1 August and 12 September. Warm weather ended half September, and temperatures decreased till half October. Night frost occurred on 20-21 October, and in the period of 11-21 November. Periods with almost daily precipitation were alternated with dry periods. The showers were most intense in summer, while drizzle occurred mostly in autumn. Snow and hail occurred during 16-22 November.

This study is sponsored by Space Research Organization Netherlands, grant EO-021.

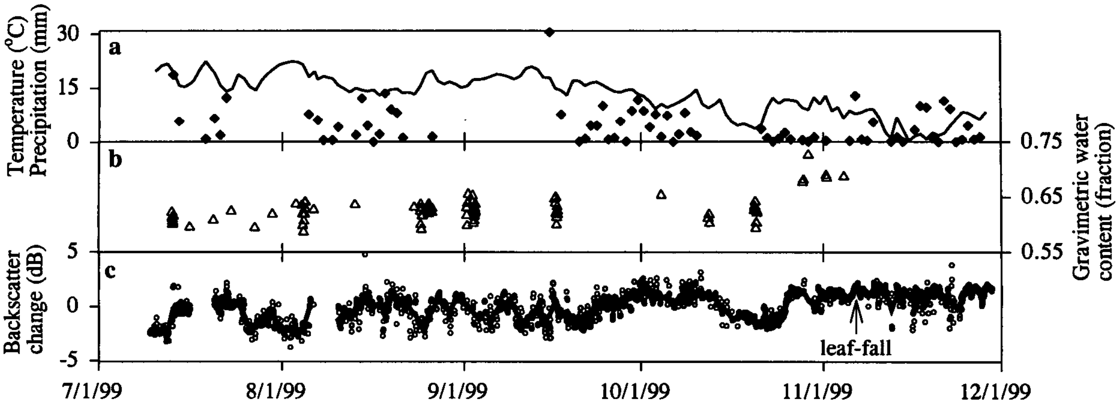

Figure 1: (a) Daily averaged temperature (line) and precipitation (diamonds), (b) gravimetric water content (triangles), and (c) hourly (dots) and daily (line) averaged backscatter change relative to the mean backscatter (c).

Fig. 1b shows the gravimetric water content of the leaves. The water content had a daily cycle with maximum water content in the evening, night and early morning, and minimum water-content in the afternoon. The observed maximum water-content gradually increased from 62 % in July till 65% in early October and next increased up to 70 %. This quick rise is interpreted as the senescence of leaves. Most leaves were shed in a storm on 6 November.

Gravimetric water-content and weather are correlated with Pearson's two-tailed test. If the high October values are excluded, then the water content is slightly correlated with modeled transpiration ($r = 0.3$, $p<0.01$). The daily maximum water content is stronger correlated with the day number ($r = 0.6$, $p<0.01$). If the high October values are included, then the correlation of gravimetric water-content with modeled transpiration decreases and the correlation of daily maximum water-content with day number increases.

The backscatter change is shown in fig. 1c. The highest recorded backscatter, 5 dB, was observed during an intense summer shower. The lowest value, -4 dB, was recorded during the warmest period of the year. The overall trend in backscatter was slightly increasing, with temporal minima in periods with no rain. The backscatter changed after leaf-fall. The radar detects at which distance the radar signal is reflected. The front of the tree reflected the radar signal strongest before leaf-fall. This backscatter decreased after leaf-fall. Leaves were thus the main scatters. The backscatter from the back of the tree is nil before leaf-fall, and increased after leaf-fall. Leaves thus also attenuated the backscatter from the branches.

The trends in backscatter from a dry, leafy tree are investigated in the following correlation analysis. The state of the tree is assessed with the wetness sensor. A new parameter is introduced in this correlation analysis. This parameter is the time went by since the last shower (duration of dryness or t_d). Table 1 shows the result. The correlation between backscatter and gravimetric water content is only significant if the high values at the end of October are included in the analysis. The daily averaged backscatter is strongest correlated with the seasonal trend in weather and water content, while it shows an opposite trend with the time after the last shower. The hourly backscatter is strong correlated with time after the last shower.

The decrease in backscatter after a shower is further investigated by selecting all showers that had a dry period of at least 6 hours after rain stopped ($n= 38$). The averaged backscatter decreased with 0.7 dB in 2 hours after the shower and remained further stable. The fast decrease is in line with the expected evaporation rate of retained rain on the surfaces of leaves [4]. As the daily averaged backscatter is also correlated with the drying time, this backscatter decrease after a shower is thus present on a time scale of hours and days.

The difference in backscatter between dry and rainy periods is quantified by splitting the observation period in rainy and dry periods, and next calculating the averaged backscatter per period. The wetness of the tree is again assessed with the wetness sensor. Table 2 shows the result. The dry-tree backscatter was in dry periods lower then in rainy periods. This difference in backscatter between dry and rainy periods decreased toward the end of the season, while additionally dry-tree backscatter increased in time. The wet-tree backscatter was higher then the dry-tree backscatter, with exception of the last dry period. The difference between dry- and wet-tree backscatter was larger in the rainy periods then in the dry periods, when the tree became wet by dew. The differences between the dry- and wet-tree backscatter also decreased towards the end of the season.

TABLE 1

Pearson's correlation coefficients ($p < 0.01$) between hourly and daily averaged dry-tree backscatter and weather and leaves water-content before leaf-fall. The daily backscatter is correlated with maximum water content of leaves.

	Day	t_d	u	T	Q_s	Q_n	H	E	m_g
Hour	0.4	-0.5	0.1	-0.4	-0.3	-0.3	0.4	-0.3	0.3
Day	0.4	-0.5	0.2	-0.4	-0.5	-0.5	0.5	-0.6	0.5

TABLE 2

Averaged dry-tree and wet-tree backscatter during rainy and dry periods before leaf-fall.

Wetness sensor	10 Jul 12 Jul	13 Jul 23 Jul	24 Jul 4 Aug	5 Aug 21 Aug	22 Aug 14 Sep	15 Sep 11 Oct	12 Oct 20 Oct	21 Oct 4 Nov
Dry	-2.2	-0.4	-1.4	-0.3	-0.4	0.1	-0.5	0.4
Wet		0.6	-1.0	0.4	-0.3	0.8	-1.0	0.5
Period	Dry	Rain	Dry	Rain	Dry	Rain	Dry	Rain

DISCUSSION

The aim of this experiment was to relate radar backscatter to hydrological properties of leaves. The backscatter is found to be related with three different processes. These processes will be discussed taking into account that the comparison of the backscatter before and after leaf-fall indicated that: (1) leaves contributed more to the recorded backscatter then branches, and (2) leaves attenuated the backscatter from branches.

The first process is a temporal increase in backscatter due to the retention of rain or dew on the surface of leaves. The observed increase due to rain was larger then the increase due to dew. This has at least two causes. Dew formation is a slower process then rainfall. The averaged amount of dew on the surface of a leaf will therefore be less then the amount of rain, and consequently the averaged backscatter increase due to dew will be lower. Secondly, it is questionable whether dew formation on the surface of the tree behaves similar as on the surface of the wetness sensor.

The second observed process is the backscatter decrease during the days after the last shower. A relation with leaf water content is not found. A hypothetical explanation is therefore a change in water content of branches. The extensible tissue of the phloem, cambium and newly derived xylem cells in the branches and stem serve as internal water-storage tissues. These reservoirs deplete during dehydration cycles [3]. As these tissues are located just beneath the surface of branches, it is likely that changes in water content of these tissues influence the backscatter.

The third process is the trend in backscatter being sympathetic with season. This increase is correlated with decreased transpiration and increased maximum water content of leaves. The latter is probably related to aging of the leaves, which causes the cell-wall elasticity to decreases, and consequently the water content changes [3]. Unlike most other tree species, the stem water content of a number of *Fraxinus* species (*F. Americana F. pennsylvanica, F. quadrangulata*) does not show an autumnal increase [7]. This process is therefore attributed to increased water content of leaves only.

It will be argued that if the internal water content of the leaves increases with season, this also influences the other two observed processes. Due to retention of rain on the surface of the leaf, the water amount of the leaf increases. This increase is relatively most if the water content inside the leaf is lowest. The backscatter increase due to rain should consequently be largest in the beginning of the season. The measurements confirm this reasoning. Leaves with low water-content also attenuate the backscatter from branches less then leaves with high water-content. Branches contribute thus relatively most to the recorded backscatter in the begin of the season. The change between the dry- and rainy-periods backscatter is attributed to a change in backscatter from branches. This difference between dry and rainy periods should therefore be largest at the beginning of the season. The observations are again in line with the expectation.

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